Example 1d: Tensile/Thermal Response of SiC/Ti-21S

This problem demonstrates several MAC/GMC simulations for a metal matrix composite. The composite is 0.25 fiber volume fraction unidirectional SiC/Ti-21S, and it has been represented with the 2×2 doubly periodic GMC repeating unit cell shown in Figure 1.1. One subcell represents the SiC fiber while the remaining three subcells are associated with the Ti-21S matrix. The material properties for both constituents are taken from the internal material database. Several applied loading cases are considered in this example. By commenting and uncommenting lines under **`*MECH`** and **`*THERM`**, results are generated for the longitudinal and transverse tensile response of the composite at both 23 °C and 650 °C.

MAC/GMC Input File: `example_1d.mac`

```
MAC/GMC 4.0 Example 1d - SiC/Ti-21S mechanical & thermal loading
*CONSTITUENTS
  NMATS=2
  M=1 CMOD=6 MATID=E
  M=2 CMOD=4 MATID=A
*RUC
  MOD=2 ARCHID=1 VF=0.25 F=1 M=2
*MECH
  LOP=1
#  LOP=2
  NPT=2 TI=0.,200. MAG=0.,0.02 MODE=1
*THERM
  NPT=2 TI=0.,200. TEMP=23.,23.
#  NPT=2 TI=0.,200. TEMP=650.,650.
#  NPT=2 TI=0.,200. TEMP=23.,650.
*SOLVER
  METHOD=1 NPT=2 TI=0.,200. STP=1.
*PRINT
  NPL=6
*XYPLOT
  FREQ=5
  MACRO=4
   NAME=example_1d_11  X=1 Y=7
   NAME=example_1d_22  X=2 Y=8
   NAME=example_1d_11t X=100 Y=1
   NAME=example_1d_22t X=100 Y=2
  MICRO=0
*END
```

Annotated Input Data

1) Flags: None

2) Constituent materials (**`*CONSTITUENTS`**) [KM_2]:

Number of materials:	2	(NMATS=2)
Materials:	SiC fiber	(MATID=E)
	Ti-21S	(MATID=A)

Constitutive models:	SiC fiber:	linearly elastic	(CMOD=6)
	Ti-21S matrix:	Isotropic GVIPS	(CMOD=4)

☞ Note: In contrast to example 1c, TREF is not included in the constituent data for this example. Thus, the temperature dependent material property data within the MAC/GMC 4.0 internal material database are employed – the code determines the material properties at the current temperature during the simulation. The temperature history is specified under ***THERM**.

3) Analysis type (***RUC**) → Repeating Unit Cell Analysis [KM_3]:

Analysis model:	Doubly periodic GMC	(MOD=2)
RUC architecture:	square fiber, square pack	(ARCHID=1)
Fiber volume fraction:	0.25	(VF=0.25)
Material assignment:	SiC fiber	(F=1)
	Ti-21S matrix	(M=2)

In this case, a repeating unit cell (RUC) architecture is selected from the MAC/GMC 4.0 internal library. Further, it is specified which materials from ***CONSTITUENTS** occupy the subcell associated with the fiber and the subcells associated with the matrix in the chosen RUC (see Figure 1.1).

4) Loading:

a) Mechanical (***MECH**) [KM_4]:

Loading option:	1 or 2	(LOP=1 or LOP=2)
Number of points:	2	(NPT=2)
Time points:	0., 200. sec.	(TI=0.,200.)
Load magnitudes:	0., 0.02	(MAG=0.,0.02)
Loading mode:	strain control	(MODE=1)

Included is the line:

```
#   LOP=2
```

By uncommenting this line and commenting the line above (LOP=1), the loading option can be switched to apply loading in the transverse (x_2) direction rather than the longitudinal (x_1) direction. As before, in directions other than that of the applied loading, the appropriate stress components are kept at zero.

b) Thermal (***THERM**) [KM_4]:

Number of points:	2	(NPT=2)
Time points:	0., 200. sec.	(TI=0.,200.)
Temperature points:	23., 23.; 650., 650.; 23., 650.	(TEMP=23.,23., TEMP=650.,650., or TEMP=23.,650.)

Much as the applied mechanical loading profile is specified with time-magnitude pairs in ***MECH**, the applied thermal loading profile is specified with time-temperature pairs in ***THERM**. Included are the lines:

```
  NPT=2 TI=0.,200. TEMP=23.,23.
#  NPT=2 TI=0.,200. TEMP=650.,650.
#  NPT=2 TI=0.,200. TEMP=23.,650.
```

By uncommenting the second line and commenting the first line, the simulation will occur at a temperature of 650 °C rather than 23 °C. For the case of applied pure thermal loading, the first two lines are commented while the third line is uncommented. This causes the code to apply a simulated heat-up from 23 °C to 650 °C. In addition, to eliminate the simulated applied mechanical loading for this case, the entirety of the ***MECH** section must be commented. Thus, for the pure thermal loading case, the ***MECH** – ***THERM** section of the input file should appear as:

```
#*MECH
#  LOP=1
#  LOP=2
#  NPT=2 TI=0.,200. MAG=0.,0.02 MODE=1
*THERM
#  NPT=2 TI=0.,200. TEMP=23.,23.
#  NPT=2 TI=0.,200. TEMP=650.,650.
  NPT=2 TI=0.,200. TEMP=23.,650.
```

c) Time integration (***SOLVER**) [KM_4]:

Time integration method:	Forward Euler	(METHOD=1)
Number of time points:	2	(NPT=2)
Time points:	0., 200. sec.	(TI=0.,200.)
Time step size:	1. sec.	(STP=1.)

5) Damage and Failure: None

6) Output:

a) Output file print level (***PRINT**) [KM_6]:

Print level:	6	(NPL=6)

b) x-y plots (***XYPLOT**) [KM_6]:

Frequency:	5	(FREQ=5)
Number of macro plots:	4	(MACRO=4)
Macro plot names:	example_1d_11	(NAME=example_1d_11)
	example_1d_22	(NAME=example_1d_22)
	example_1d_11t	(NAME=example_1d_11t)
	example_1d_22t	(NAME=example_1d_22t)
Macro plot x-y quantities:	ε_{11}, σ_{11}	(X=1 Y=7)
	ε_{22}, σ_{22}	(X=2 Y=8)
	temperature, ε_{11}	(X=100 Y=1)
	temperature, ε_{22}	(X=100 Y=2)
Number of micro plots:	0	(MICRO=0)

In this example, four macro (repeating unit cell level) x-y plot files are generated, one for the σ_{11}-ε_{11} stress-strain response, one for the σ_{22}-ε_{22} stress-strain response, one for the temperature-ε_{11} response, and one for the temperature-ε_{22} response. For the case of longitudinal applied loading (LOP=1) and the thermal loading case, the σ_{22} values written to the x-y plot file will all be zero. Similarly, for the case of transverse applied loading (`LOP=2`) and the thermal loading case, the σ_{11} values written to the x-y plot file will all be zero.

7) <u>End of file keyword</u>: (**`*END`**)

Results

Figure 1.5 presents plots of the composite response to the applied global longitudinal (along fiber the fiber direction) and transverse (perpendicular to the fiber direction) (see Figure 1.1) strain loading at both 23 °C and 650 °C. The right hand side of the plot represents the stress-strain response in the direction of the applied loading, while the left hand side of the plot shows the strain response normal to the loading direction (i.e., the Poisson effect). These results show that the composite is significantly stiffer in the longitudinal fiber direction compared to the direction transverse to the fibers. When the loading is applied transverse to the fiber direction, the resulting Poisson effect strain is small due to the presence of the continuous fibers normal to the loading direction. At elevated temperature, the composite is much softer and exhibits more inelastic deformation than at room temperature. Figure 1.6, which is a plot of the composite's longitudinal and transverse thermal response to a globally stress free heat up, shows that the composite exhibits greater strain during the thermal loading in the transverse direction compared to the longitudinal direction.

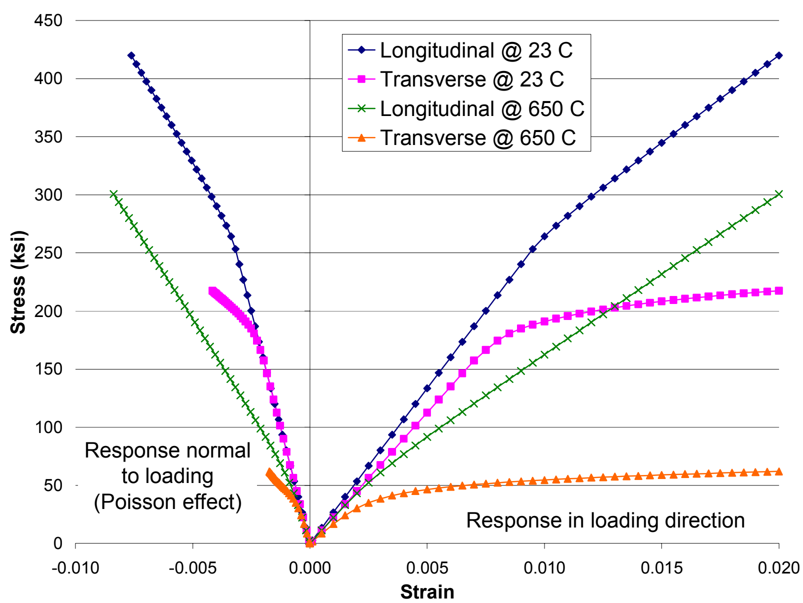

Figure 1.5 Example 1d: plot of the simulated longitudinal (along the fiber direction) and transverse (perpendicular to the fiber direction) stress-strain response of a 25% SiC/Ti-21S composite at 23. °C and 650 °C. The strain response normal to the loading direction (i.e., Poisson effect) is also plotted.

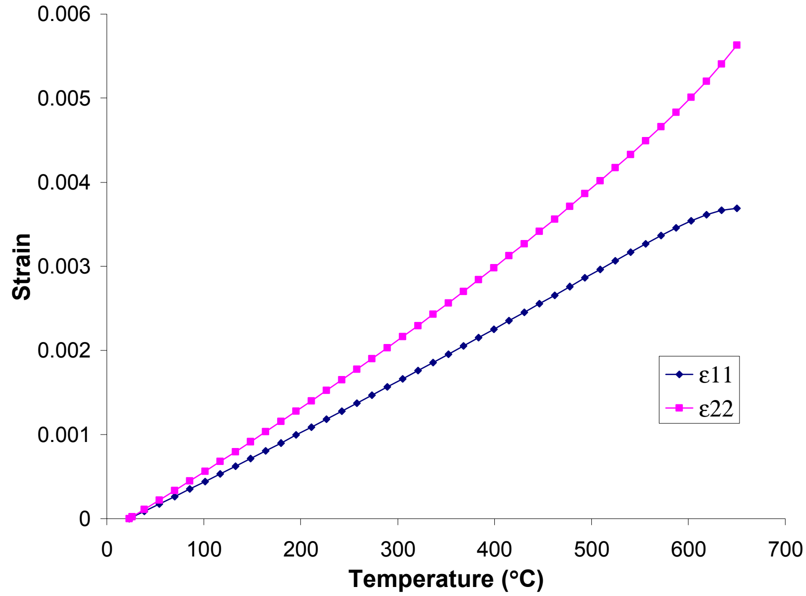

Figure 1.6 Example 1d: plot of the simulated longitudinal and transverse temperature-strain response of a 25% SiC/Ti-21S.